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Analysis of the Principle and Application for Deployable Bridge in Japan

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Abstract:

As a matter of fact, Japan's early learning of bridge construction through the incorporation of Western knowledge influenced its subsequent industrial development and economic progress. Due to its earthquake-prone geographic location, Japan has conducted in-depth research on rapidly deployable foldable emergency bridges. This study focuses on the study of deployable folding bridges using the Japanese scissor-like structure. The results of the study analyze the facilities of the scissor-like structure and list some of the cutting-edge applications of the structure and the principles are also analyzed in terms of specific application scenarios. The advantages of deployable bridges are their emergency response capability and ease of transportation, as well as limitations such as susceptibility to weather and high economic costs. The purpose of this paper is to analyze the current state of deployable contraction bridges and to consider future prospects based on cutting-edge technologies that will enable them to better utilize their advantages.

Keywords: Scissor-like element; deployable bridge; Japanese bridge.

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1. Introduction

The scissor-like elements, which are advantageous in architecture and space applications, are renowned for their compactness and expandability [1]. In order to solve river crossing problems and handle traffic loading difficulties, this study suggests a new articulated scissor-like elements type bridge arrangement that includes a scissor-like element (seen from Fig. 1 [2]). Strategic integration of suitable combinations of structures can efficiently address the inherent static and dynamic difficulties of this structure, despite its vast number of nodes and susceptibility to horizontal axial vibration. It has been shown by theoretical and numerical studies that the addition of reinforcement elements improves the bridge's safety and ability to support both static and dynamic loads [3].

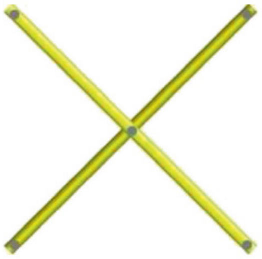

Fig. 1 Scissor unit [2].

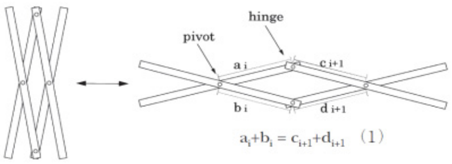

Fig. 2 Scissor-like element basic form [4].

Furthermore, because of their rotating and telescopic characteristics, deployable scissor structures can achieve enormous geometric deformations. To aid in the construction of asymmetric and multi-centered structures, a novel design procedure combining geometric and analytical techniques is offered. Specifically, a methodology grounded in the fundamental design principles of angle-scissor structures is presented, enabling the generation of expanded and fully expanded structures on single-center and multi-center curves and lines. As a case study, a numerical model of a monocentric curvilinear sunshade is also provided as shwon in Fig. 2 [4].

Furthermore, because scissor-like elements are deployable, they are interesting for a variety of applications. Deployable structures with remarkable structural strength and flexibility include scissor-like elements. Advancements in element configurations, joints, and actuation techniques have been shown in recent studies to enhance the stiffness, flexibility, and usefulness of structures. However, it is emphasized that before scissor-like elements are widely applied in industry, more structural analysis research is required. From the conclusion of the Edo period to the start of the Meiji period, Japan expanded its bridge construction technology by incorporating cutting-edge Western technology. The emergence of Western and traditional technology is said to have had a major impact on the direction and nature of modernization in Japan, where the Industrial Revolution was sparked by outside forces. For example, traditional technologies that were either inherited or localized had a big impact on iron-making technology, flood control projects, and water conservation initiatives. In terms of bridges, Western expertise in building iron bridges was brought to Japan during the early Meiji period, and by blending with traditional methods, it significantly influenced later modernization. The goal of this research is to create a bridge system that is swift, mobile, self-supporting, stable, and expandable for use in a range of locations [5-7]. However, basic technology—more especially, the quick development of disaster recovery systems, has not yet advanced to a point where it is necessary. The author proposed the idea of a „scissors-type deployable bridge" based on both an investigation of the damage caused by the Chuetsu earthquake in 2004 and basic research into buckling and deployment structures.

The 'smart bridge' design idea was implemented in 2009 with the aim of creating infrastructure that can withstand natural disasters. By successfully building a human-trafficable bridge prototype with a scissor-like element, the business established the fundamentals and technology of folding bridges. In order to produce a prototype mobile temporary bridge that can be quickly deployed as part of a restoration technology to remove „village isolation" in the case of a disaster, research is now being done at Hiroshima University (seen from Fig. 3) [6].

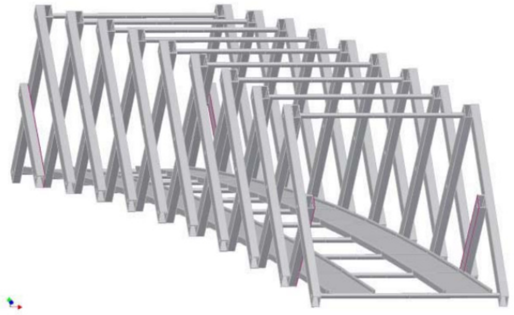

Fig. 3 Conceptual diagram of the development of a foldable bridge by Hiroshima [6].

Japan has been hit by numerous natural disasters, causing severe damage to its infrastructure and disrupting traffic flow. To address this, the government has built emergency bridges, but these are time-consuming and labor-intensive. This study proposes an extending temporary emergency bridge to address this issue. The article analyzes expandable bridge structures, their operation, and their effectiveness in emergency response and changing traffic patterns. It highlights safety, durability, and economic considerations using real-world examples and test findings. The study also highlights the limitations of existing technology and suggests areas for further research to improve future uses. Automation and artificial intelligence are expected to improve the effectiveness of expandable bridge operation and maintenance, reducing the likelihood of failure. Real-time condition monitoring can also be used for preventative maintenance programs. Research is also being conducted on the integration of new energy technologies like solar and wind power. Expandable bridges have the potential to be a versatile urban planning tool, accommodating changing traffic patterns and evacuation routes in emergencies.

2. Concepts for Structure

The deployable structure is a flexible structure which it can change from a compact stowed state to a desired deployed state that is pre-set by the user when activated by a command. Deployable structures can also be subdivided into expandable, erectable, and reconfigurable structures, which can become the structure that meets the user's expectations in various situations. In this paper, for the design of bridge structures, scissor structures are the retractable deployable structures used for bridge frames. Scissor structure is a widely used deployable structure where the bars are connected by hinges and the position of the hinges determines the type of movement or structural mechanism of the overall structure. In addition, the high stiffness and flexibility of the shear structure makes it a suitable choice for use as the main structure of bridge structures [8]. With regard to technical support for this structure, bridges can be analyzed using non-destructive testing techniques. These include radar, ultrasonic, infrared thermography and magnetic particle testing. Through this type of testing, the safety and stability of the structure can be assessed without causing structural damage to the target, and the internal state and remaining life of the structure can be understood, so as to eliminate potential safety hazards and provide technical support for the construction of bridges. In addition, the elastic strain energy driven composite structure can be used as a reference for this structural study. The composite structure has simple structure, light weight, high integration, as well as good mechanical properties. This as a bridge structure has a great advantage over the traditional shrinkage structure [9-11]. In terms of structural scenarios, deployable scissor structures can be used in the construction of shelters based on their high stiffness. In addition, the structure is used in the aerospace industry and in the construction industry.

3. Principle in Bridge Designs

Composite systems with both mechanical and structural qualities are known as deployable structures. They are made by putting together fundamental components in particular ways. These systems are distinguished by their easily assemble able nature, small size, and flexible shapes. The final form and intrinsic qualities of the structure are ultimately determined by the particular sort of basic unit used. Of them, the scissor-like element, i.e., a "X-shaped" component made up of two freely rotating bars around a connecting joint, offers a great deal of potential for further study because of its stiffness, precision, high shrinkage ratio, and consistent deployment. Additionally, a scissor-like element unit's endpoints can be hinged to those of other units, allowing for the creation of more intricate deployable linear array structures. In engineering, the applications and specific examples of these structures are of interest to researchers in a wide range of fields, including biological structures, architecture and aeronautics. The largest sectional force is applied to the fixed end of this mobile bridge during its extension because it acts like a cantilever beam until its leading edge reaches the opposite side. The bridge changes from a cantilever to a simply supported beam once the tip is fastened to the opposing bank, with the highest sectional force shifting to the middle of the span [12].

After the preliminary load tests and analysis validated the structural safety, erection tests were carried out in a real river in Hongo-cho, Fukuyama, Hiroshima Prefecture [13]. Fig. 4 illustrates the circumstances. The goal of designing the prototype mobile bridge was to minimize the amount of time and labor needed for on-site erection [4]. The drive system on the main body is hydraulic. This makes it easier to move the unit to the location on a trailer and to automatically dismount, deploy, and stow it afterwards. Moreover, the device has an automated slab-laying mechanism that is activated in tandem with the bridge body's elongation. The main body was brought in a trailer, as seen in the picture, and the erection was finished automatically by a hydraulic drive system. The weight of the storage frame of the main unit serves as a counterbalance during deployment (about 20 kN), and it was verified that steady erection is achievable even when the unit is cantilevered. The erection process involved roughly five persons, including the guide, and took about four hours from delivery to erection completion. A 1500cc class passenger car (vehicle weight: approximately 14 kN) was driven in the small car driving test. It was established that non-linear behavior, such as buckling and yielding of the members, was not seen, even if the specifics of the strain data collected in each member are not included here. Additionally, it was discovered that the bridge construction, falling within the elastic range, was possible under the presumptive design conditions. The bridge's structural viability was verified.

Fig. 4 Experimental conditions of erection on a real river: bridge transport (upper left), Erection status elongation status (upper right), after construction (lower left) and vehicle driving tests (lower right) [4].

4. State-of-art Architecture

The curved scissor mechanism is different from a simple scissor-like mechanism as illustrated in Fig. 5 [10]. Typically, a normal shear mechanism consists of identical shear units arranged in a linear direction so that they can be contracted and deformed in a fixed direction. A planar scissor mechanism with a compound curve solves this problem. In the case of curved TSMs, unlike shear mechanisms that can only change in two dimensions in a single curve using a rigid straight link, curved TSMs are composed of multiple units with different polarities and translations, allowing them to change in different dimensions, as well as being able to undergo twisting changes. For this type of practical application, this arc TSM is characterized by a higher degree of flexibility and a wider range of applications than the normal single-threaded shear mechanism. It also has good prospects for use in areas such as connecting channels and support frames. Its flexibility allows it to be utilized in a variety of situations. Further research on its structure should focus on its mechanical properties as well as the strength of the material, so that it can better utilize its advantages when used as a component.

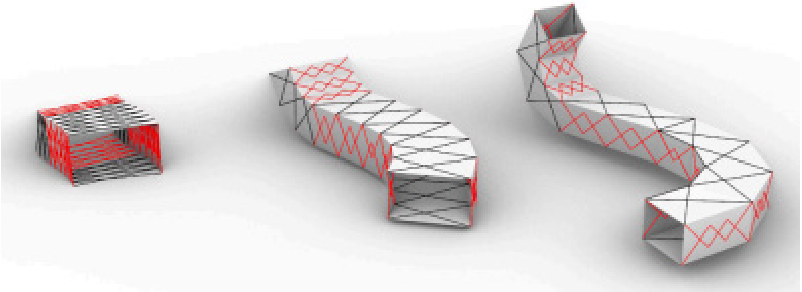

Fig. 5 Simulation model [10]

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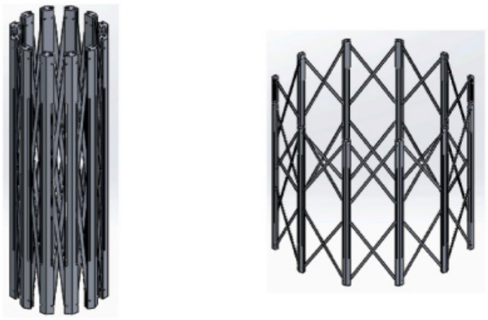

Fig. 6 Truss inside antenna [8].

The double scissor mechanism of the ring structure is a structure that is currently used in aerospace engineering as presented in Fig. 6 [8]. This mechanism is a double-scissor structure, based on a ring shape, used to make a space deployable antenna truss. The structure consists of a number of double-scissor structures, where each unit module is a planar structure consisting of two scissor structures. Each unit module forms a ring so that the antenna is circular in shape. The scissor angles of all the unit modules are kept constant during the linking process. Compared to the single scissor structure, the double scissor structure has high stiffness and better stability. During the installation of the truss, a slider will be fixed to the middle interface to move the whole structure in the vertical direction to realize the installation of the whole frame. This design is used for spacecraft antennas. Antennas are required to realize the connection between the earth and the universe, which has led to a great increase in the demand for space antennas. In order to increase the gain of the antenna, increasing its diameter is a method. This structure is characterized by high stiffness, high reliability, high precision, and high folding rate. Due to its stowable and deployable characteristics, and the fact that its diameter can be increased to a large extent when it is used, the antenna‘s utilization efficiency is increased, and it is a reasonable frontier application of a deployable structure.

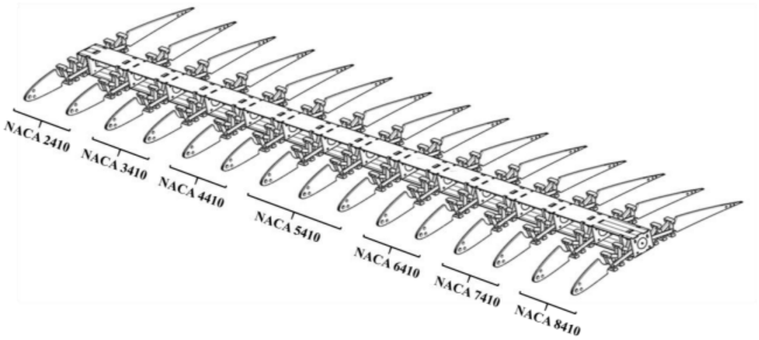

Fig. 7 Wing internal structure [9].

Fig. 7 is the use of deployable scissor structures for airplane wings [9]. A deformable wing can be assembled using a scissor-like structure. The internal structure consists of several parts, in the center of which is the spar part, which is fixed and combines several components, and the brakes are located inside the spar. Each of these elements is organized in three parts, which include a continuous scissor structure, a leading-edge assembly, and a trailing edge assembly. The two components are located at the front and rear of the scissor-like structure and are fixed in position. In the overall structure, the deformation of the scissor-like structure affects the overall shape of the wing. For the significance of its structural use, the scissor-like structure deforms and transforms according to the current wind speed and air pressure, adjusting to the shape of the wing that best suits the current environment. The advantages of this structure are its stability and high stiffness, as well as its good variability, which makes it suitable for the internal structure of the wing. For more in-depth research, attention should be paid to the material of the wing, as well as the material of the outer surface of the wing, so that the research object can have a good performance under different environmental conditions [14-16].

5. Limitations and Prospects

Extensible bridges face challenges such as manufacturing technology limitations, system complexity, and cost. These bridges require tensile-strong and flexible materials, but environmental factors like age, moisture, temperature fluctuations, and salt corrosion can cause deterioration. The complexity of the system increases the likelihood of maintenance issues and failures. Cost is a major concern, especially for larger buildings. Extensible bridges are also more expensive to design and install than standard fixed bridges, especially for larger structures. In seismically active areas like Japan, expandable constructions must be resistant to distortion and vibration, posing additional issues related to earthquakes and climate change. Research on smart materials like shape memory alloys and self-healing materials is being conducted to improve flexibility and durability. Automation and artificial intelligence are expected to improve bridge operation and maintenance, reducing failure rates. Real-time condition monitoring can also be used for preventative maintenance programs. Additionally, research is being conducted on integrating new energy technologies like solar and wind power [16].

6. Conclusion

To sum up, this study is about the study of deployable bridges with scissor structures. As a commonly used structure, scissor structures are essential in the construction of bridge structures in this paper. The wide range of applications can be drawn from today‘s cutting-edge design of scissor structures in the overall design of bridges. The limitations of this bridge are the high cost of transportation and construction, as well as environmental and weather-related problems, for which material and maintenance issues need to be addressed. For the future of this technology, one can consider combining it with solar and wind energy to reduce energy consumption, with urban planning to make it more flexible, and with the introduction of new materials to solve the maintenance problems. Finally, the study of this retractable bridge can greatly reduce the pressure on urban space and will also play a crucial role in emergency situations, such as natural disasters.

Author Contribution

All the authors contributed equally and their names were listed in alphabetical order.

References

[1] Ma X, Li T, Ma J, et al. Recent Advances in Space-Deployable Structures in China. Engineering, 2022, 17: 207–219.

[2] Yu X, Yang Y, Ji Y, Li L. Experimental Study on Static Performance of Deployable Bridge based on Cable-Strengthened Scissor Structures. Hindawi, Advances in Civil Engineering Volume 2021: 11,

[3] Hiroshi I, Yoshio H. On the direction of modernization of bridge construction technology in Japan: a structural comparison perspective. JSCE, 1996, 536(4-31): 69-85.

[4] Shuichi O. Development of new type emergency bridge with rapid construction structure. JSCE, 2016, 62.

[5] Ichiro A, Yoshikazu T, Masatoshi N, Yusuke F, Yuki C. Development of the prototype of a new emergency bridge based on the concept of optimized structure. JSCE, 2010, 56.

[6] Ichiro A. Open experiment for vehicular traffic on emergency smart temporary bridges that can be erected rapidly. Construction planning, 2013, 13: 4.

[7] Jian J M, Cher S T, Shahrin M, Ahmad R Z A. State-of-Art review on deployable scissor structure in construction. Structures, 2022, 42: 160–180.

[8] Mariyam S, Naveed Ur R, Naseem A. Design, kinematics and dynamic analysis of a novel double – scissors link deployable mechanism for space antenna truss. Results in Engineering, 2024, 22: 102251.

[9] Yeeryung C, Gun J Y. Variable camber morphing wing mechanism using deployable scissor structure: Design, analysis and manufacturing. Advances in Aircraft and Spacecraft Science, 2022, 9(2): 103-117.

[10] Seita T, Junpei K, Yoshiyuki N, Makoto O. Composition of curvilinearly extendable tubular scissor mechanisms. International Journal of Solids and Structures, 2022, 250: 111673.

[11] Li B, Wang S M, Tan U X. Buckling analysis of planar linear uniform deployable structures consisting of scissor-like element in space under compression.□SCIENCE□CHINA□ Technological Sciences, 2021, 64(3): 493–507.

[12] Khongkham C, Ichiro A, Yuki C. Smart design of coupling scissors-type bridge. Structures, 2021, 30: 206–216.

[13] Liu T, Bai J, Fantuzzi N, Zhang X. Thin-walled deployable composite structures: A review. Progress in Aerospace Sciences, 2024, 146: 100985

[14] Chen J. Application of non-destructive testing technology in road and bridge engineering. Modern Engineering Project Management, 2024, 3: 12.

[15] Daniel S H L, Olga P L, Seung D K. Study of the connection joint for scissor-type deployable structure for the possible application in emergency evacuation shelter. Proceedings of the First Conference Transformables. The Honor of Emilio Perez Piñero, 2013.

[16] Lu R, Judd J. Field-Deployable Fiber Optic Sensor System for Structural Health Monitoring of Steel Girder Highway Bridges. Infrastructures, 2022.